

Take the Plunge: A STEM Camp Centered on Seafloor Science

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ABSTRACT

While most of the Science, Technology, Engineering, and Mathematics (STEM) efforts center on classroom programs, many lack hands-on activities that allow students to experience phenomenon-based learning and produce a complex scientific project. To meet this need, we developed week-long STEM summer day camps for two age groups: rising third to fifth and sixth to ninth graders. Campers learn about seafloor exploration through multiple hands-on, technology-rooted, team-based activities. At the end of the week, campers design and present research missions for an actual seafloor feature, incorporating hypotheses, methods, and operations.

Motivation

In the past decade there has been a push for STEM learning activities in K-12 and collegiate education. This aim is to foster a more technical, well-versed and informed community, spark advances that spur the economy, develop improvements in security, and ignite innovations in health and environmental sciences among other national and global needs and interests (National Research Council 2012). Our aspiration was to contribute to this educational objective by developing a week-long, STEM summer day camp (Seafloor Science and Remotely Operated Vehicle (SSROV) Camp (www.ssrovcamp.org)). The camp provides an out-of-school opportunity that engages students through problem-solving skills and teamwork via hands-on STEM projects. Camp activities are grounded in current seafloor research and exploration expeditions and have a reach beyond the camp. The field of seafloor exploration captures the imagination, develops intellectual and teamwork skills, is relevant to a range of potential career choices, and is conducive to making connections between desktop activities and the environment (Humphris 2009). These components are recognized criteria for a productive out-of-school educational program (National Research Council 2015).

A premise for the camp is that seagoing scientists depend on detailed plans, innovative sensors and samplers, and the knowledge and resources to use and repair instruments at sea. Decades of experience working in the field of oceanography have taught us that within the marine research field

there is a demand for technology-savvy professionals who can communicate with scientists, and for scientists who understand the technology they use for their research. This experience is conveyed to the campers who learn about the deep ocean, research equipment used at sea, and the roles and responsibilities of numerous occupations that are required for a successful expedition. Camp activities expand the minds of the campers by putting them in exciting real-life roles. Campers experience increased confidence and improved problem-solving and communication skills, as they engage with others in both imaginary and fact-based exercises.

Our aim is to promote problem-solving skills and teamwork through a hands-on STEM learning opportunity that culminates in the development of a proposed seagoing research expedition. These student-proposed expeditions are grounded in the geology, biology, chemistry, and hydrogeology of particular seafloor settings. Challenging science and technology-based activities merge both disciplines and raise awareness of their interdependencies. Seafloor science provides the backbone for phenomenon-based learning, whereas hands-on activities emphasize project-based pedagogy. In addition to science- and technology-based activities, the camp introduces complex operational problems and unusual operational events. These operational challenges make campers think and work together to find creative solutions. This is, perhaps, one of the most future-relevant aspects of the camp. Like professional ocean research, SSROV Camp emphasizes purposeful engagement and vision, planning and operations, teamwork and execution, and discovery and problem solving.

One desired outcome for the camp is personal development. While most campers are regular users of consumer technology (smart phones, tablets, computers, gaming, some programming, etc.), in camp they develop deeper technical knowledge and more nuanced skills. They learn about building technology based on a foundation of scientific knowledge, rather than just using available technology as it is presented to them. The second aspect of personal development is the broader reach provided by the interns. High school or early collegiate students mentor the campers

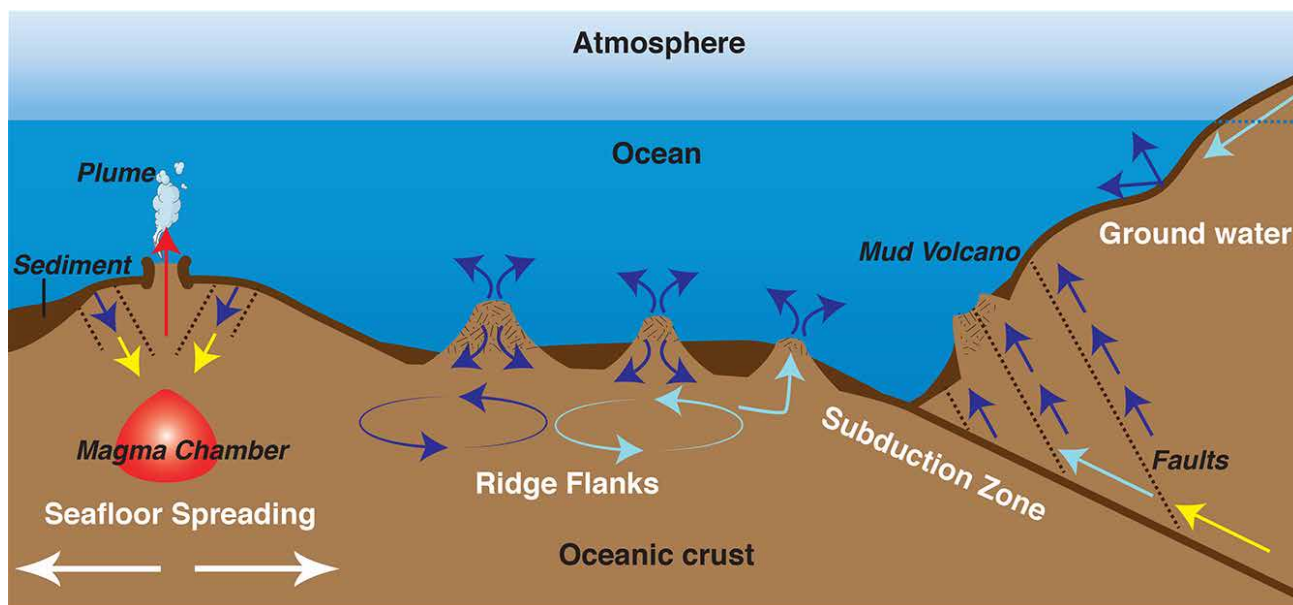


FIGURE 1. Cartoon of primary geologic processes that result in the discharge of fluid from the crust to the ocean. Fluid discharge at spreading centers is driven by magmatic heat, whereas fluid discharge on ridge flanks is driven by lithospheric cooling and differences in crustal topography and sedimentation. Fluid discharge from subduction zones is driven by compaction and dewatering of hydrated minerals. Groundwater discharge into the ocean requires a permeable aquifer and pressure head. Warmer colored arrows represent warmer fluids. Courtesy of SSROV Camp

and help them with problem solving. This is often the interns' first exposure to real-life STEM careers, which we encourage them to pursue. Combined, SSROV Camp provides an environment where campers can be with like-minded peers and mentors, supporting each other in academic and technologically creative pursuits.

Why Seafloor Exploration?

Most experiences with the ocean are either on or in the ocean, but rarely under the ocean. Even exposure under the ocean is typically limited to snorkel depths or those of commercial submarines that are not only depth limited, but also generally available only near tourist destinations. The deep sea is dark and remote, engaging the imagination, especially given the unique life forms that have been recovered from depth (e.g., angler fish and giant squid). While the water column in the deep sea contains many unknowns, and new species are discovered on almost every remotely operated vehicle (ROV) dive (Sherlock et al. 2017), the seafloor provides an avenue to engage campers in learning about geologic, biological, chemical, and physical processes—and the advanced technologies that are required to collect samples and data from such a remote and harsh environment.

While much of the seafloor is covered by sediment with limited macrofauna (Glover and Smith 2003), there are oases of organisms and minerals where changing conditions are observed during yearly visits by ROVs and submersibles (e.g., Van Dover 2000). Such oases, for example, are observed along seafloor spreading centers (Figure 1). Here magma from the mantle heats seawater that circulates through the permeable upper basaltic crust forming hydrothermal vents. Some vents are black smokers and support microbial communities via chemosynthesis, which is the basis of the food web for local animals such as tubeworms, crabs, and mussels (e.g., Fisher et al. 2007; Tivey 2007). Seawater also circulates through the oceanic crust in many other settings including 1.) the ridge flanks (covering most of the abyss) with a volume of fluid discharge from the oceanic crust that is commensurate with the discharge of the world's rivers to the ocean (Fisher and Wheat 2010); 2.) subduction zones (Saffer 2015); and 3.) continental groundwater discharge (Sawyer et al. 2016) (Figure 1). Combined, these settings offer a range of geologic settings, mineral deposits, fluid compositions, and biota—any of which may spark a camper's imagination and interest.

Because these settings are typically found at a depth of 2500m or deeper, advanced technologies are necessary to collect samples and data. These technologies include pressure tolerant components, high voltage electronics, robotics, and sensors. These items require mechanical, electrical, and software engineering skills, and operational specialists to design and deploy sensors and samplers on the seafloor, navigate surface and underwater vehicles, and program autonomous underwater vehicles. Thus, with the introduction of one general scientific umbrella, a range of technologies and potential occupations are introduced to the campers.

Components of SSROV Camp

Camps are currently designed for two age groups, students entering third to fifth grades (three- or six-hour duration depending on the venue) and students entering sixth to ninth grades (eight-hour duration). Both camps have four primary foci: 1.) the scientific method, 2.) engineering practices, 3.) operational realities, and 4.) mentoring. The overarching scientific theme for both curricula levels is the development of an expedition to elucidate aspects of fluid discharge from the ocean crust. For example, at the end of the week, groups of two to three campers in the sixth to ninth grade level present a complete "proposal," which is the foundation for peer-reviewed science. These presentations are based on 1.) a multi-beam bathymetric map of a particular seafloor feature with fluid discharge; 2.) two fact sheets related to the general structure of the crust and the specific fluid chemistry, geology, and biota that correspond to that specific setting; and 3.) hands-on activities, seafloor videos, demonstrations,

homework, and in-class discussions. Proposed research plans from the upper level teams are complete with hypotheses, methods, and operations. Proposals from the lower level have been less structured, but hit upon the major themes.

Engineering practices are promoted with each hands-on activity and presented in the context of the overall scientific theme or a particular aspect of a mission that is based on answering a scientific question. Both camps have a general schedule and theme that changes daily (Table 1). Within each theme are several topics that are emphasized with two hands-on activities in the morning and two in the afternoon. Each activity is preceded by a short discussion that places the activity in the context of actual seagoing operations, including images and videos of seafloor activities. The campers then complete the activity, which includes age appropriate mathematics, programming, and scientific rigor, often with informational sheets that include additional directions and questions. At the end of the activity, one or two of the groups answer a series of questions in front of the camp. Group discussions address what they did, how they did it, what worked, what didn't work, and how they would change what they did to meet the desired goal or a goal of their choosing.

There is some duplication in themes between the two age groups, but activities differ, consistent with grade-appropriate vocabulary and explanations. Embedded in these themes is a connection to seafloor geology, biology, chemistry, and hydrogeology. Activities are based on a series of hands-on electrical, mechanical, and software engineering

Day	Theme	Topic
Monday	ROVs	Circuits, Motors, Buoyancy, ROVs, Manipulators
Tuesday	Autonomous Underwater Vehicles and Geology	Circuits, Programming, Rovers, Seafloor Geology
Wednesday	Sensors, Operations, and Fluid Discharge	Sensors, Data Loggers, Seafloor Elevators, Fluid Discharge
Thursday	Benthic Biology and Operations	Transects, Quadrates, Benthic Biology, Seafloor Elevators
Friday	Operations and Proposals	Data Interpretation, Operations, Exploration Board Game, Geo-pardy, Proposal Presentations

TABLE 1. Overview of themes and topics for the sixth to ninth grade level camp. Actual activities make the most of the particular venue. For example, camps may spend most of one day on a pier (lake or ocean) or at a community swimming pool, affecting the order and duration of specific activities. The third to fifth grade level camp includes about half of these topics. Additional topics for the third to fifth camp include bathymetry, navigation, evolution, and seafloor scientific drilling.



FIGURE 2. Campers program BOE Bots (Board of Education Bots, Parallax, Inc.) to understand operational issues associated with autonomous benthic rovers within the context of a prescribed feature on the seafloor. In this case, the campers navigate around Axial Seamount, which is located off the coast of Oregon (US) and is “wired” through the NSF-funded Ocean Observatories Initiative (www.ooi.washington.edu). Courtesy of SSROV Camp

problem-solving actions, each with an aspect of mathematics. Activities include: mechanics of using a manipulator to collect samples or pick up instruments from the seafloor, developing integrated systems to complete designated missions, and fabricating and calibrating sensors. For example, campers are given “unknown” samples for which they determine the concentration based on the calibration curve that they generate from their sensor circuit and a series of samples with known concentrations. Another example of an activity is one that focuses on operations and science conducted by seafloor rovers. Campers use computers to program small “underwater” rovers to complete designated patterns, thus learning how to program. Next, campers program rovers on a prescribed path related to their geologic setting, moving “seafloor instruments” from one site to another for “recovery” (Figure 2).

Each activity incorporates operational realities. Operational activities provide campers with an understanding of how to get sensors and samplers to the seafloor, navigate on the seafloor, and deploy and recover samplers and sensors through the design and operations of ROVs, autonomous rovers, and elevators. The latter are a means to deploy large or heavy instrument packages on the seafloor or recover samplers and sensors without recovering the underwater vehicle. Operational realities include a myriad of problems that arise, from a rover that is slightly misaligned to an ROV

that loses a thruster. Operations also include logistics such as choosing the closest port to the site, the number of days to reach the site, the number of days on site, costs, etc.

Mentoring also is instrumental in the camp experience. The camp staff works with numerous counselors who are high school and early collegiate students. High school students are currently recruited from the Monterey Academy of Oceanographic Science and the Robotics Club at Presentation High School (the latter is a school for young women). While the counselor’s primary role is to ensure the safety of the campers, they also mentor the campers (Figure 3). While not revealing how to reach the most optimal solution(s), counselors provide advice to stimulate thought and guide campers as needed. The counselors also represent the gender and ethnic diversity of the community, providing role models for the campers.



FIGURE 3. High school students mentor teams of campers, suggesting potential pathways to complete an activity or a design criteria inspired by the campers. Here the campers design a manipulator system that attaches to a PVC ROV that was designed, built, and tested earlier in the day. Courtesy of SSROV Camp

Assessment

Multiple techniques for program assessment are employed to revise our teaching/learning approach, and for campers to reflect on and integrate current activities with previous ones. Of these techniques, the only enumerated approach is the pre- and post-camp questionnaires. These questions were designed to assess knowledge and provide a measure of successful and non-successful activities. The post-camp questions for the sixth to ninth grade level camp are:

1. Name three types of vehicles that are used to study the seafloor.
2. List the main components of an ROV.
3. Describe the adaptations your team made to its ROV and why you made these changes.
4. What is a breadboard and how is it used?
5. How would you calibrate a temperature sensor?
6. How do particles affect light transmission through the water, and what is the consequence of turbidity on data transmission?
7. Draw a seafloor elevator and label its parts.
8. Name and describe your team's seafloor geologic feature. How do fluids discharge through the oceanic crust in this setting?
9. How would you quantify the number and density of organisms (fish, crabs, snails, etc.) on the seafloor?
10. What are three key operational activities that must be considered before embarking on an expedition to study or explore the seafloor?
11. What camp activity did you enjoy the most? Why?
12. What camp activity did you enjoy the least? Why?

About 50% of campers (39 of 78 total campers) in 2016 could correctly answer three of ten questions on the first morning of the camp. At the end of the week-long camp, more than 85% of campers could correctly answer eight of ten questions and more than 66% of the campers could answer all the questions. In 2016, the most enjoyable activity was split between the ROV and rover activities. The least favorite activity in 2016 centered on the use of quadrats to count organisms on the seafloor. This activity was revised before it was implemented in 2017.

Four other aspects of assessment are not formally enumerated. First, formative assessment and reflection are integrated within each activity. Upon completion of an activity, one or two of the student teams answers a series of questions to reinforce their understanding. Questions focus on the mechanics of the activity, and two questions that are more broadly based such as "How did it work/not work?" and "How is this technology used in daily life?" The latter is designed to increase awareness of their surroundings. Second, homework,

which is assigned on the first three nights of the camp, is discussed the following morning. Homework also is designed as a medium to instigate discussion among the campers and their families at home, for campers to recount what they did, and to introduce a new topic that will be the focus of the following day. Third, campers play GEO-parody, based on the concept of Jeopardy, which tests their knowledge of the seafloor, sensors, and operations that were presented in the camp. Lastly, teams make three presentations to the camp. One is based on the geologic and hydrologic setting of their particular seafloor environment. The second focuses on the biology and chemistry associated with fluid discharge at their site. The last presentation—at the end of the week—is one in which teams propose a mission to explore and investigate their particular seafloor environment (see Figure 4 on page 7), complete with hypothesis, methods, and operations. For each of these four assessment styles, camp staff (and camp counselors) asked additional questions to promote inclusion of all team members and to relate concepts to the broader oceanic environment.

Future Directions and Challenges

We are about to embark into our fifth year of offering SSROV Camps. Each year, the camp enrollment grows and challenges change. Camps are currently offered for two age groups and have expanded from six camps in 2016 (78 campers and 10 interns) to eight camps in 2017 (140 campers and 13 interns). This growth in the number of camps resulted from the development of a third to fifth grade camp, which was introduced in 2017. In response to parent and camper requests, we plan to expand the program to a more advanced skill level for students entering eighth to tenth grades. However, challenges in developing a more advanced program include: the cost in salaries to develop activities, and the purchase and modification of materials for the camp. For example, materials for sixth to ninth grade level camp cost ~\$25,000 to purchase materials and prepare them for a 24-person camp.

Our near-term goal is to continue to expand to new locations. This presents challenges in finding suitable venues and keeping the camp fiscally solvent. We recognize the need to pay instructors, interns, and counselors competitively, especially given the limited number of camps that are offered each summer in certain geographic regions. We also recognize that areas that are largely populated by lower income families will require financial assistance, leading to the need for monetary contributions to provide camps in such areas. Last year about 15% of the campers were provided a scholarship to attend the camp.

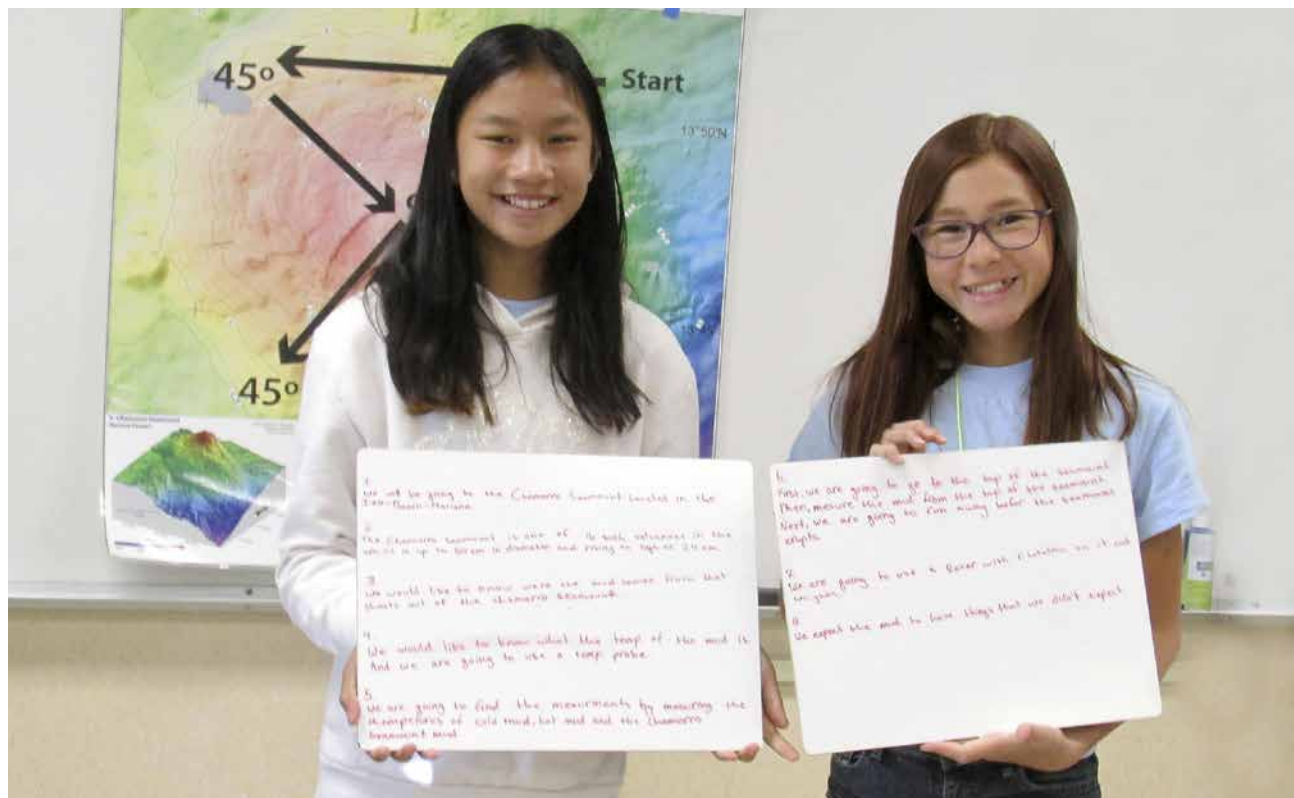


FIGURE 4. A team of campers describes their proposed research expedition to South Chamorro Seamount to an audience of fellow campers and their parents at the end of the week. South Chamorro Seamount is one of a dozen serpentinite mud volcanoes in the Mariana forearc. These are the largest mud volcanoes on Earth and fluids that discharge from them have a pH of 12.5, which is the pH of household bleach (Wheat et al. 2008). Courtesy of SSROV Camp

Ultimately our long-term vision is to create a sustainable, nationwide program that spurs excitement for learning about the deep-sea environment and helps young people, especially those who might not otherwise have these experiences, to see themselves in the role of the explorer, scientist, engineer, technician, or operational specialist.

A major strength of the SSROV Camp is that it was developed and is currently taught by seagoing professionals and based on actual science drivers and mission operations. However, bringing the camp to additional locations poses new challenges, such as hiring suitable middle and high school teachers to lead the camps. Although these individuals have more experience in the classroom than the team that developed the camps, these teachers lack the exploration experiences and anecdotes offered by seagoing professionals that make the experience more real. To counter this inevitability, we have developed a series of videos that instructors can use to address a range of potential questions and to provide direct ties to actual operations.

An additional obstacle that researchers face in developing a summer camp is a general lack of financial support. We, however, have been fortunate in having several funding streams that made SSROV Camp a reality. Lastly, some of the new activities that were developed for the camp will be incorporated into the RETINA (Robotic Exploration Technologies IN Astrobiology) Program (Wheat et al. 2013) to provide options and/or additional materials for classroom teachers who wish to provide a more comprehensive program.

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